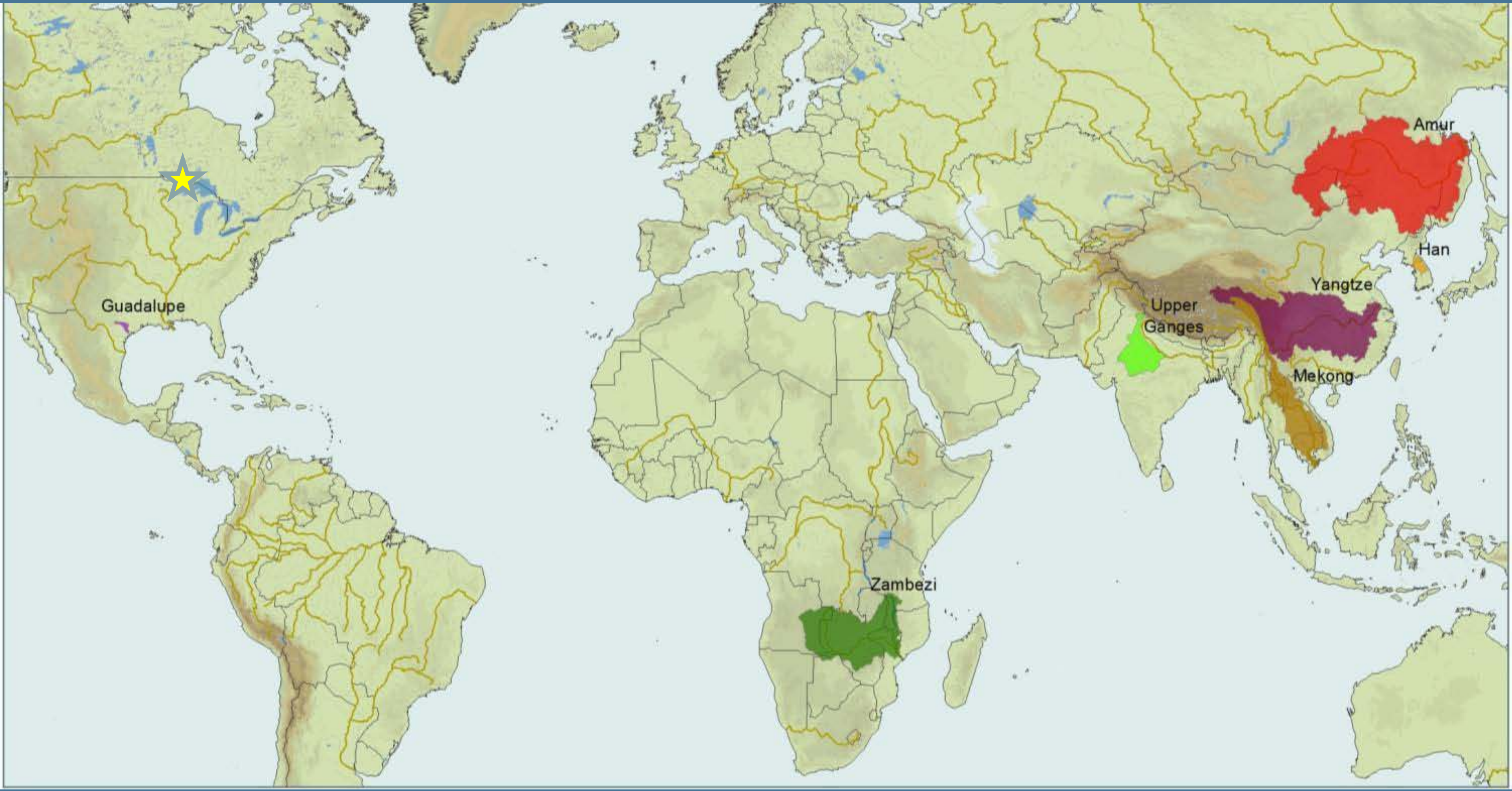
Environmental flows and the restoration of the Zambezi Delta of Mozambique

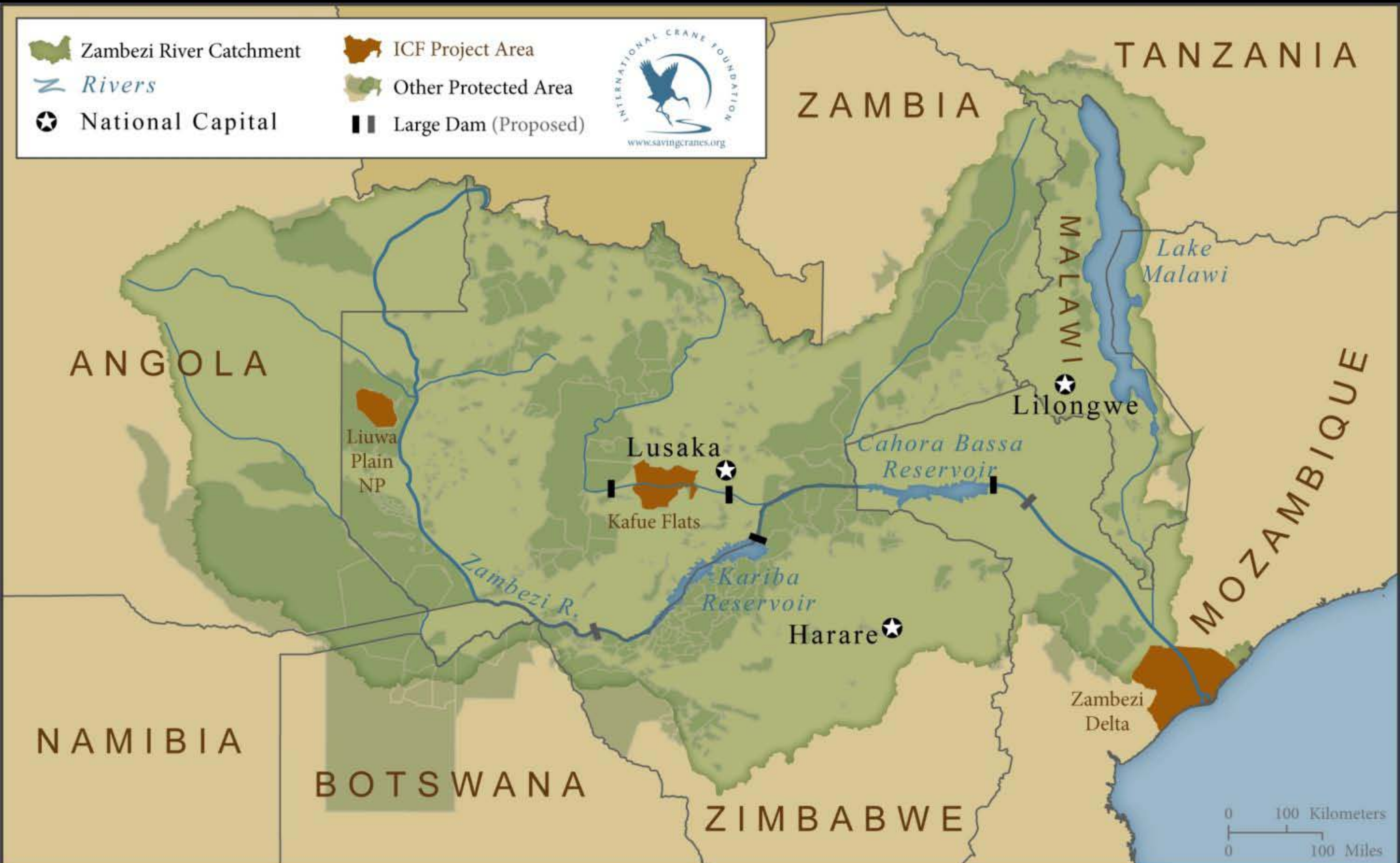
Richard Beilfuss
International Crane Foundation

Seven Rivers



Overview

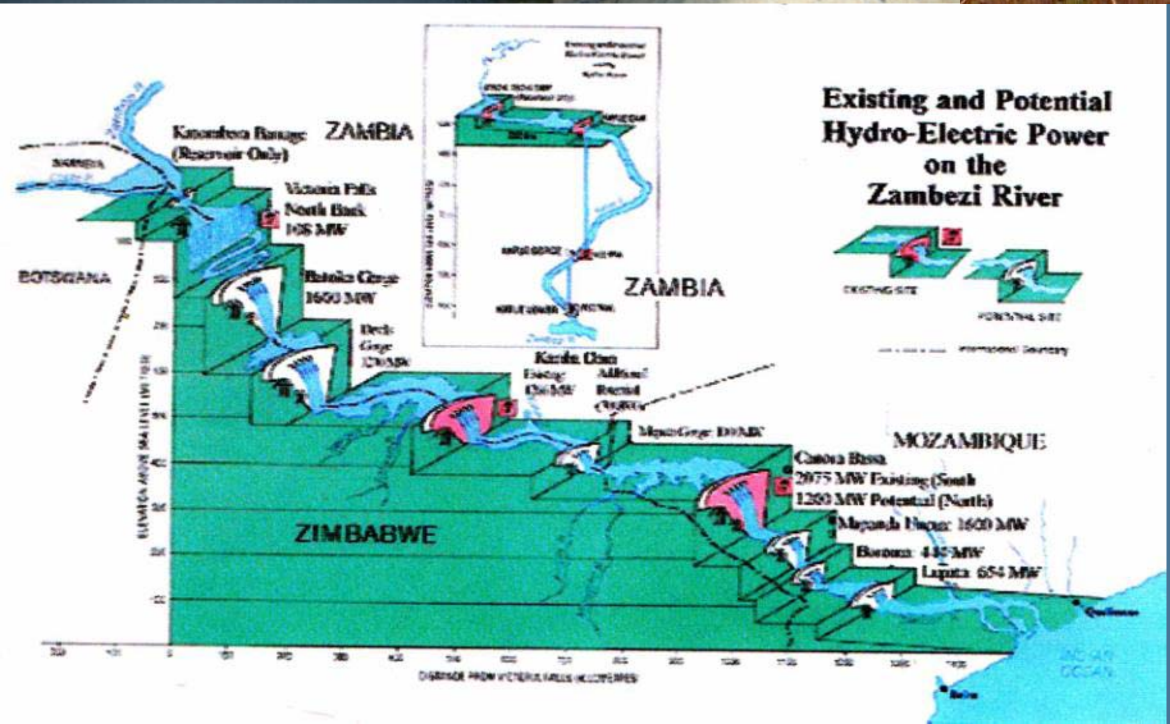
- Zambezi Basin overview
- Key findings of the Zambezi Delta research and management program
- Implementation of environmental flows and restoration of the Zambezi Delta



1,390,000 km^2 watershed connecting eight countries in southern Africa

Zambezi basin waters are the lifeline of southern Africa

Hydropower



Installed

3530 MW (mainstem)

>5000 MW (basinwide)

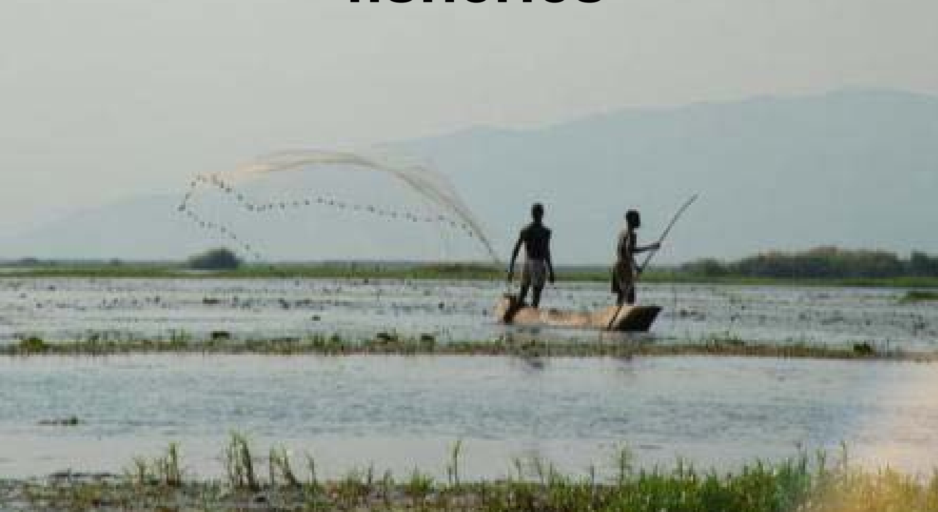
Potential

>13 000 MW (basinwide)

Reservoir development

- Sport & commercial fisheries
- Tourism/recreation
- Trophy hunting
- Crocodile farming
- Irrigated agriculture

Floodplain and riverine fisheries

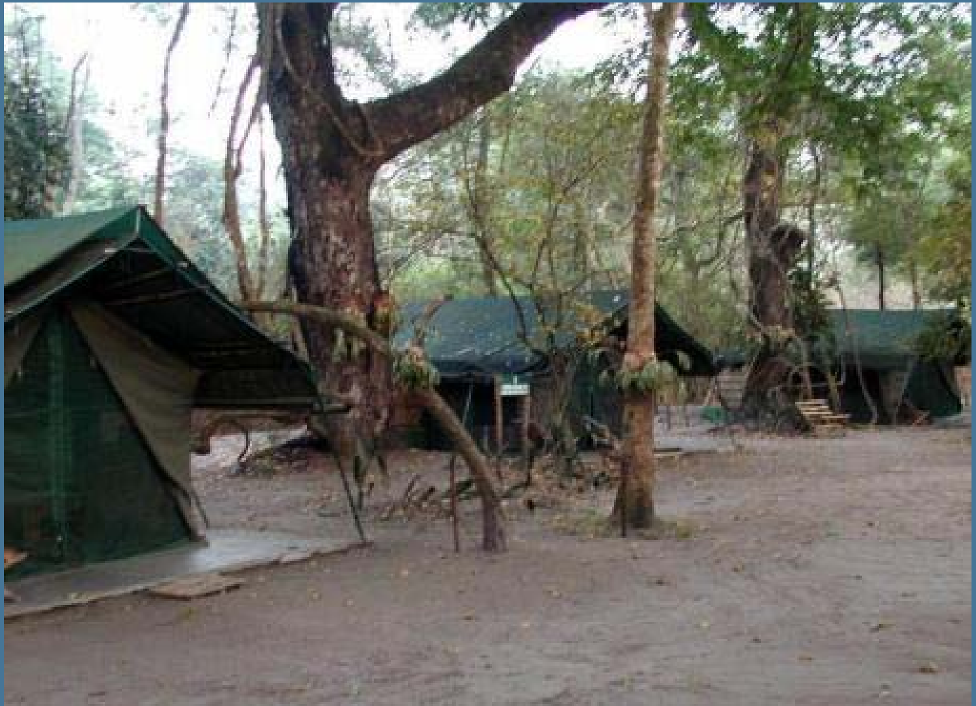


Flood-dependent agriculture (floodplain rice, riverbank food, and cash crops)

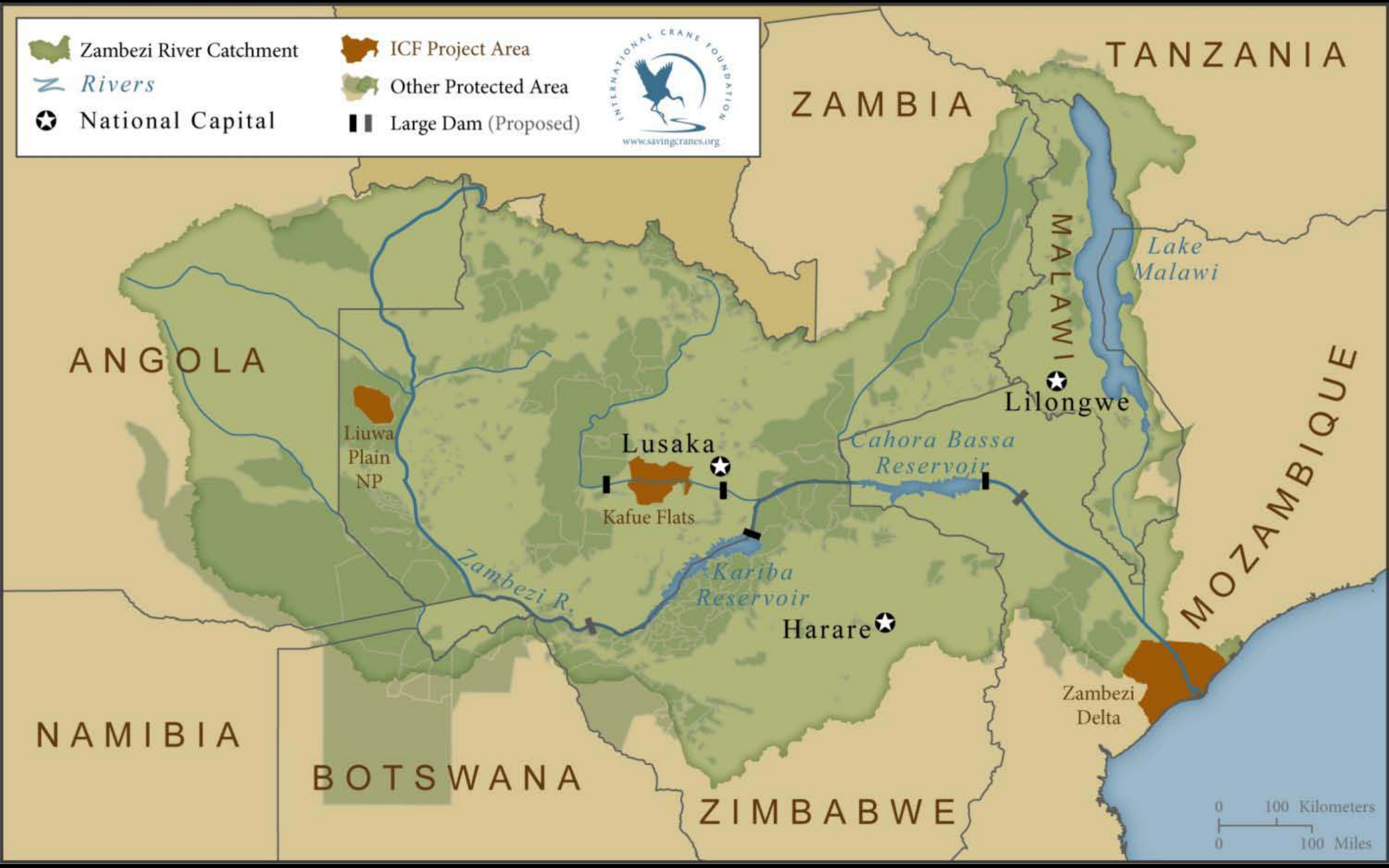
Sugar production for export and potential bio-fuel development

Export prawn aquaculture—natural and managed production systems

International hunting safaris and ecotourism



Other subsistence and small-scale commercial products

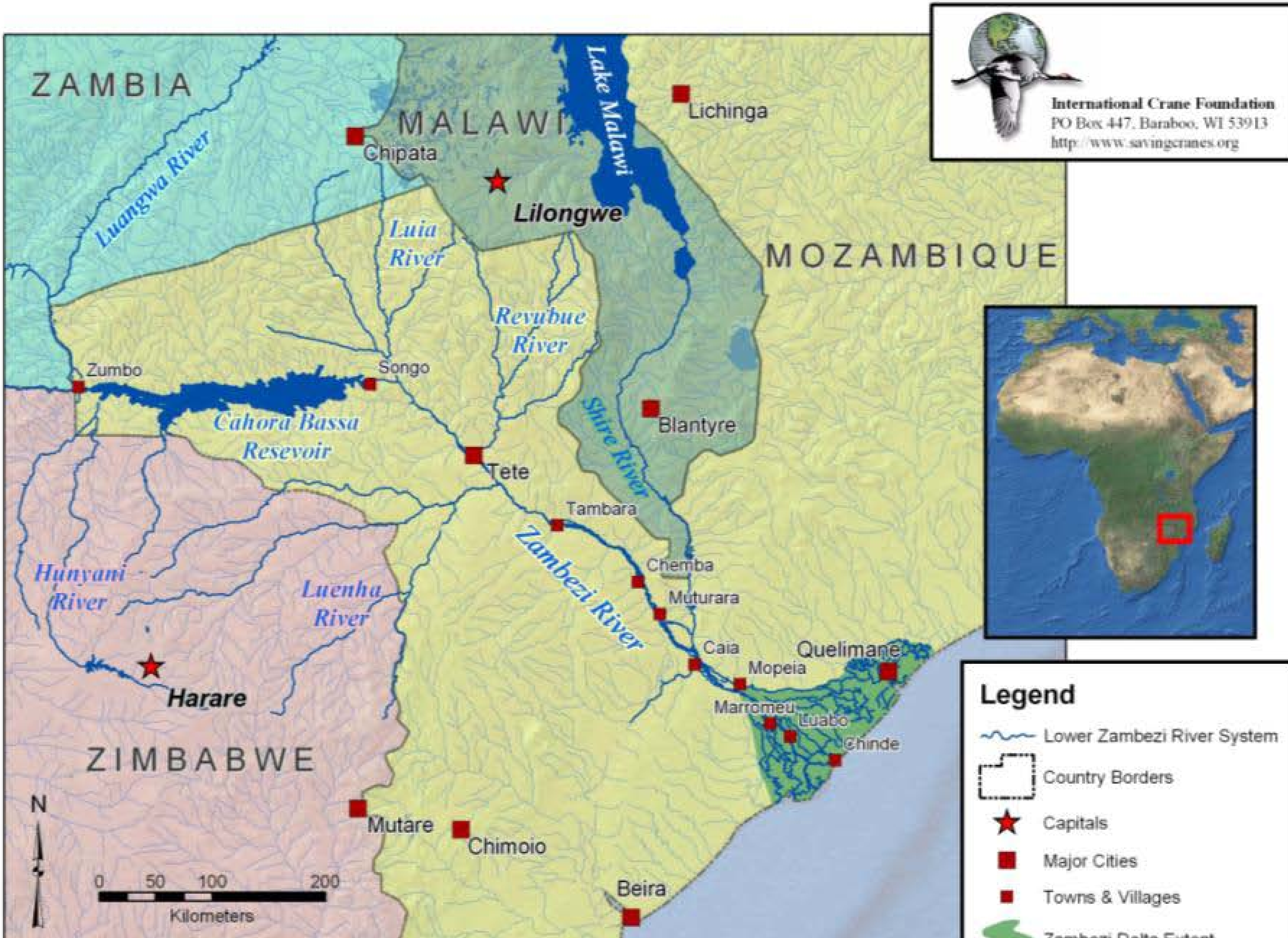


River-dependent Protected Area Network

Busanga Swamps
Chobe Swamps
Kafue Flats
Liuwa Plain
Lower Zambezi
Mana Pools
N&S Luangwa
Zambezi Delta




Eight Wetlands of International Importance--Ramsar Convention



The Lower Zambezi River and Delta

Cahora Bassa Dam and Reservoir

Contribution of downstream runoff from plateau tributaries and Shire River basin

Zambezi Delta floodplain (18 000 km^2)

10 years after construction…

"Cahora Bassa has the dubious distinction of being the least studied and possibly least environmentally acceptable major dam project in Africa."

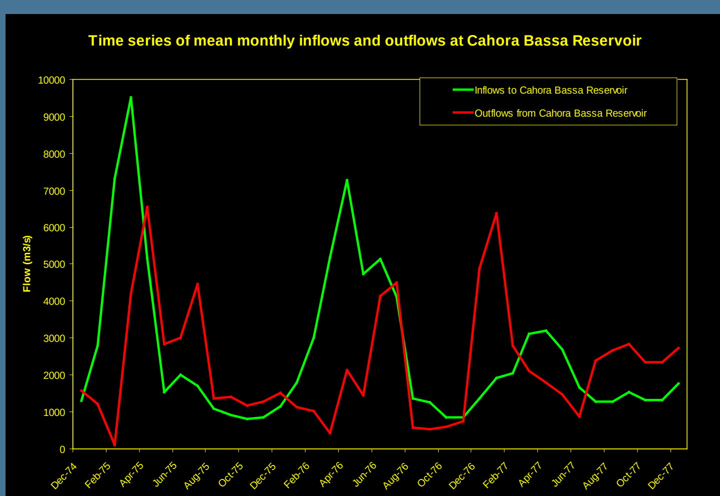
-- U.N. Food and Agriculture Organization (1985)


Obstructions to river-floodplain connectivity caused by roads, railways, and flood protection in the Zambezi Delta

Zambezi Delta research and management 1995-present

1. How have changes in the Zambezi River flow regime affected biodiversity, ecosystem services, and human livelihoods?

2. How can adverse changes be ameliorated through environmental flows within operational realities?



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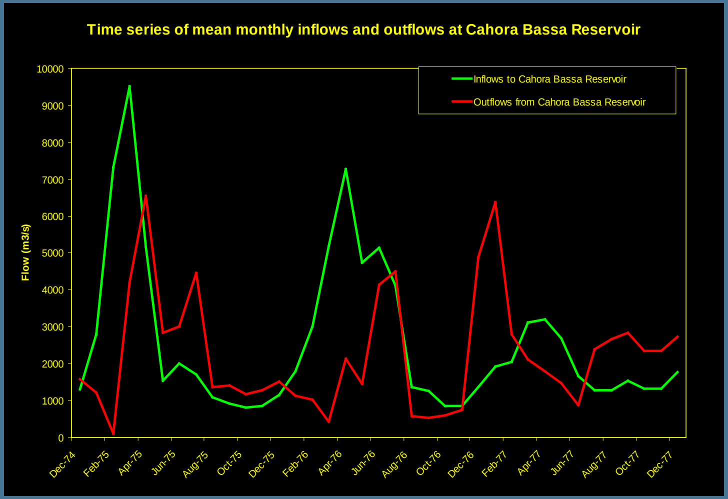
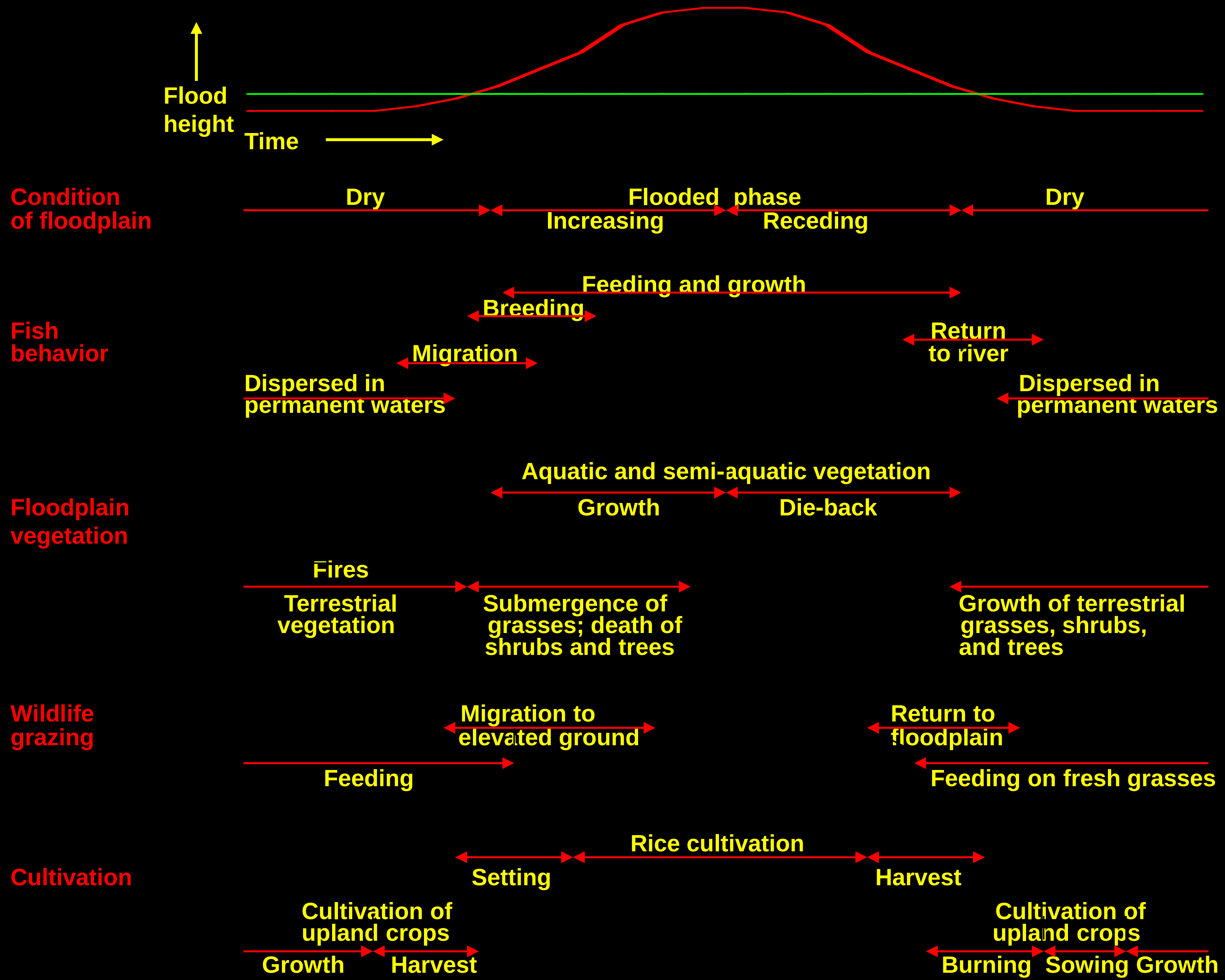



Flood height
Time
Condition of floodplain
Dry
Flooded phase
Increasing
Receding
Dry
Fish behavior
Feeding and growth
Breeding
Return to river
Migration
Dispersed in permanent waters
Dispersed in permanent waters
Floodplain vegetation
Aquatic and semi-aquatic vegetation
Growth
Die-back
Fires
Terrestrial vegetation
Submergence of grasses; death of shrubs and trees
Growth of terrestrial grasses, shrubs, and trees
Wildlife grazing
Migration to elevated ground
Return to floodplain
Feeding
Feeding on fresh grasses
Cultivation
Rice cultivation
Setting
Harvest
Cultivation of upland crops
Growth
Harvest
Cultivation of upland crops
Burning
Sowing
Growth

Characterizing flow regime and patterns of hydrological change

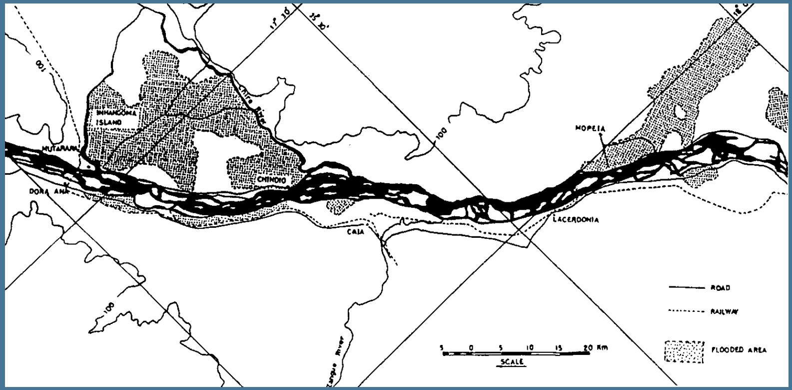
•Daily flow series in the Zambezi Delta covering pre-regulation (1930-1957), post-Kariba Dam (1958-1974), and post-Cahora Bassa Dam (1975-present), and reconstituted monthly flow series covering 1907-2007.

•Assessment of hydrological alteration (Range of Variability Analysis)

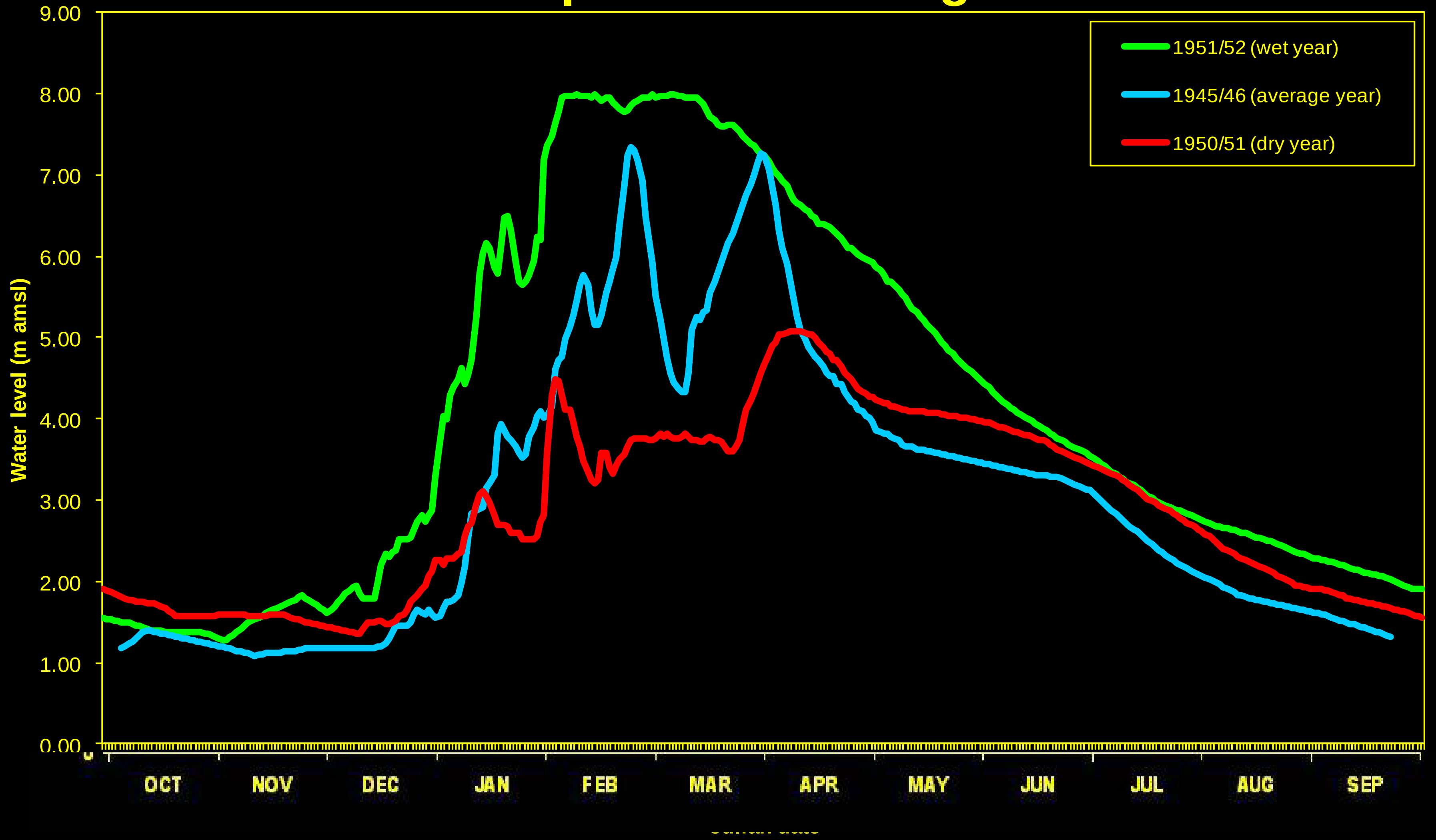
•Flood frequency analysis

•River-floodplain hydraulics

•Zambezi Delta water balance and patterns of floodplain inundation (magnitude, timing, duration, frequency)

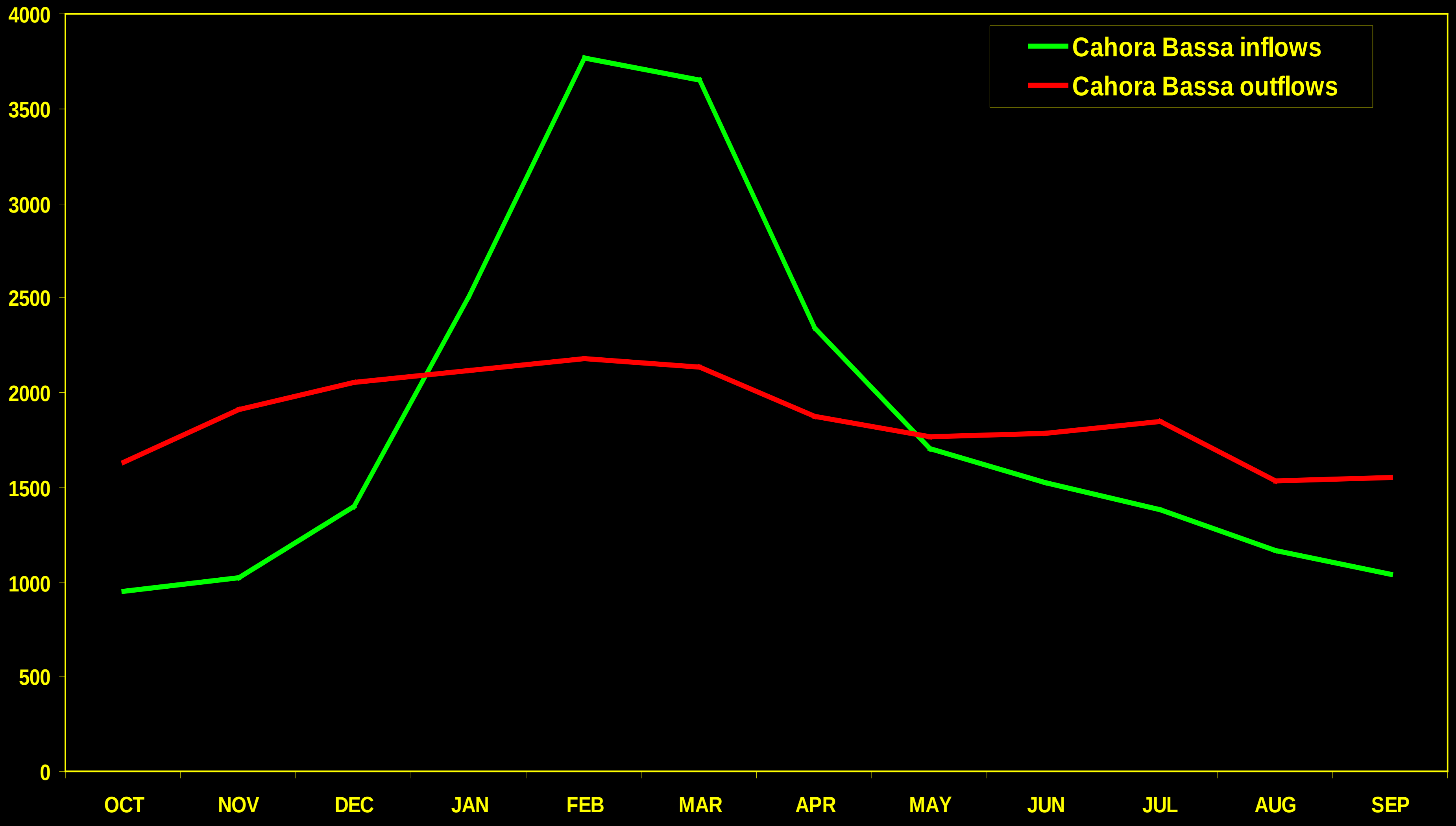


Average daily water levels in the Zambezi Delta prior to river regulation



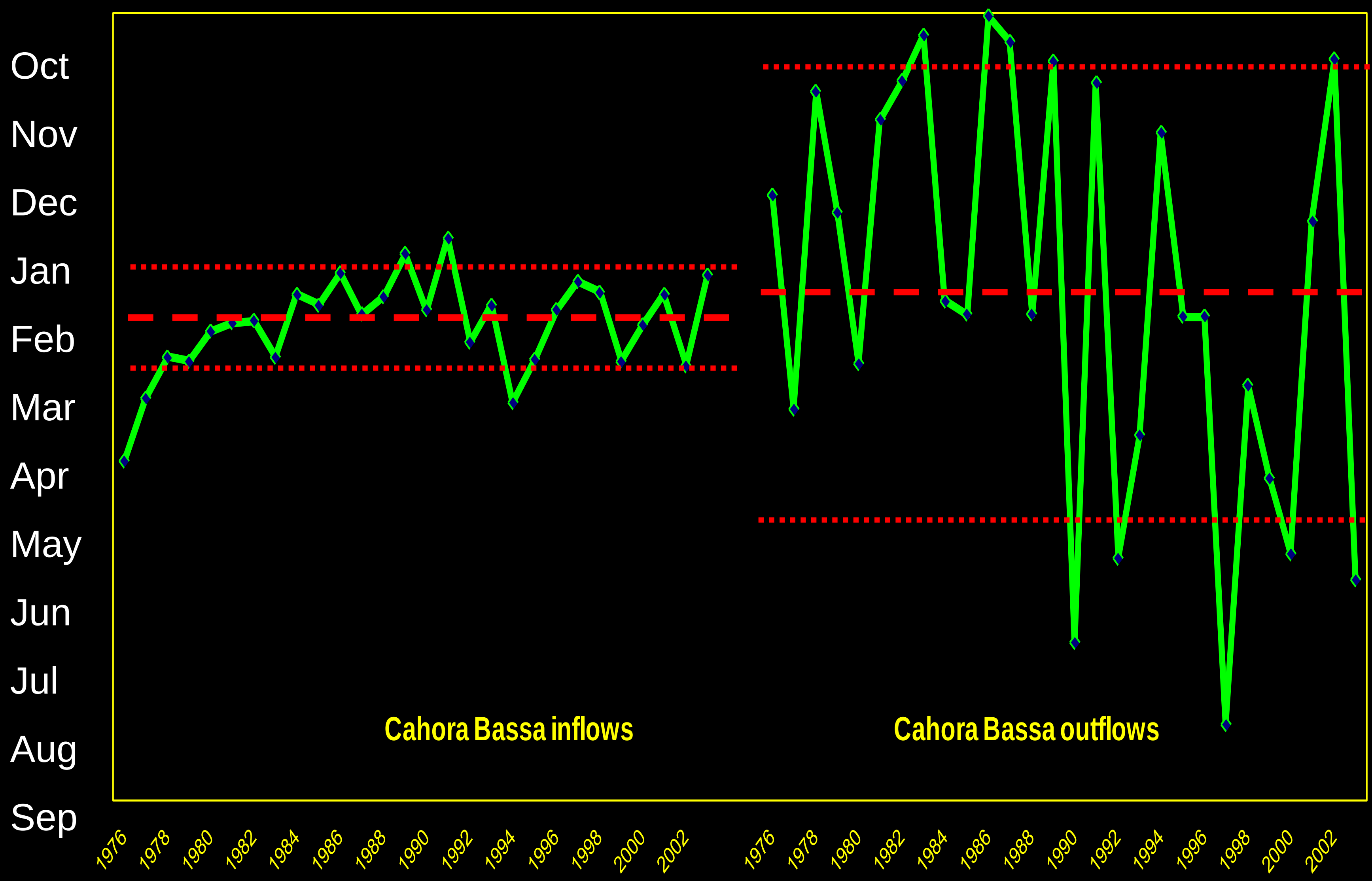
Beilfuss and Santos 2002

Cahora Bassa reservoir, mean monthly inflows and outflows, 1974-2004



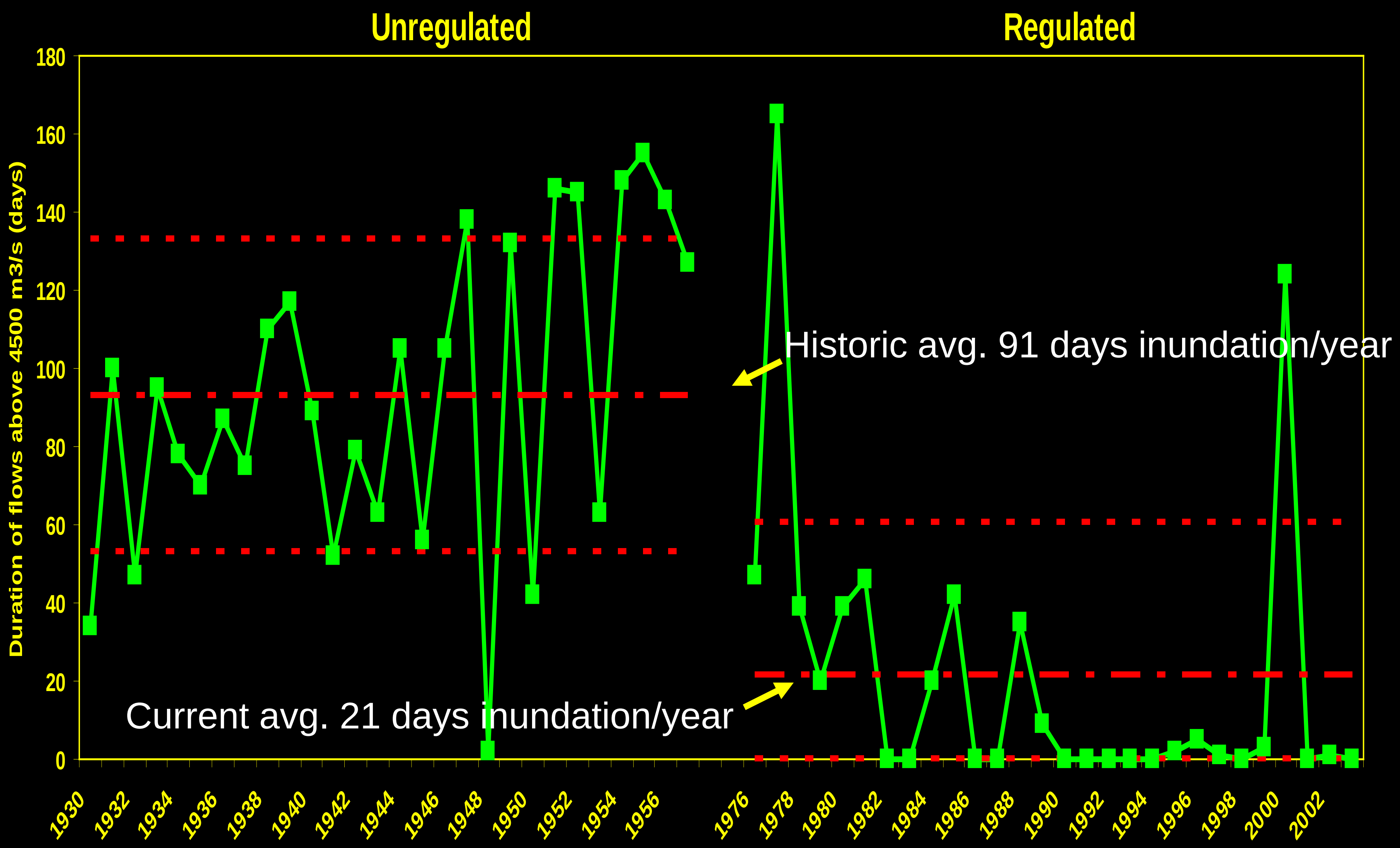
Beilfuss and Bento 2006

Cahora Bassa reservoir, timing of peak annual inflows and outflows, 1975-2004



Beilfuss and Bento 2006

Duration of inundation in the Zambezi Delta under pre-dam (1930-1958) and post-dam (1975-2004) conditions



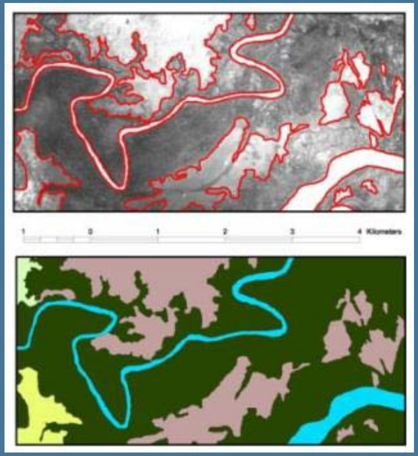
Beilfuss and Bento 2006

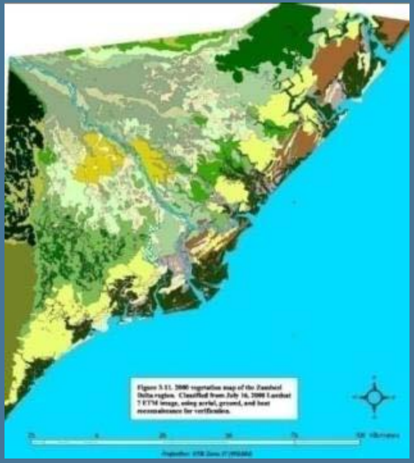
Linking Zambezi flow regime to geomorphology and vegetation dynamics

•Mapped and quantified changes in vegetation cover over time (1960-2000) using field sampling, aerial surveys, archival aerial photography, and remote sensing

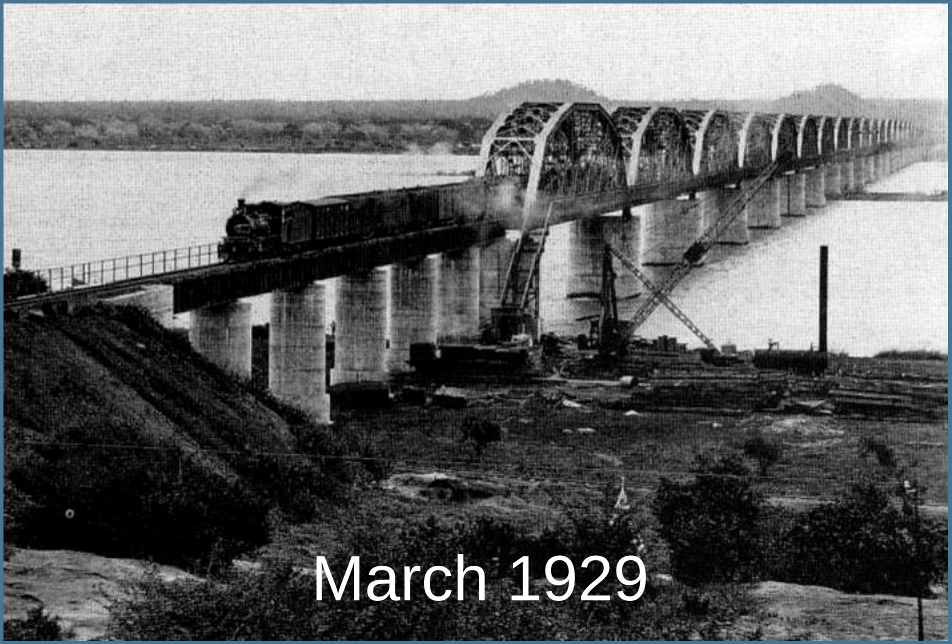
• Permanent vegetation transects (cover, rooted freq)

• Factors affecting vegetation change at different scales—flood, fire, grazing regimes





Adverse changes in river geomorphology



- Continued downcutting of mainstem river channel
- Bankful discharge only exceeded during exceptional runoff
- Stabilization of sandbars
- Riverbank erosion

Changes in vegetation cover in the Zambezi Delta, 1960-2000

Vegetation classification unit	Area in hectares			
	1960	2000	change	%change
Acacia thicket on delta floodplain	40000	45000	5000	13
Acacia savanna on delta floodplain	113000	140000	27000	24
Borassus palm savanna on the delta floodplain	9000	8000	-1000	-11
Hyphaene palm savanna on delta floodplain	72000	86000	14000	19
Hyphaene palm savanna and associated species on outwash sands	29000	34000	5000	17
Secondary grassland/savanna/thicket on the channel shelf and levee	28000	31000	3000	11
Seasonally wet tussock grassland mosaic on delta floodplain	158000	122000	-36000	-23
Perennially wet stoloniferous grassland mosaic on delta floodplain	125000	118000	-7000	-6
Papyrus and deepwater swamps in permanently flooded channels	91000	84000	-7000	-8
Saline grassland mosaic with Phragmites reedswamp	127000	133000	6000	5

Beilfuss et al. 2001

Continued bush encroachment onto floodplain, linked also to expanding tse-tse infestation

Infestation of waterways due to reduced flushing---
reducing water movement into the floodplains

Mangrove die-back and coastal shelf erosion due to reduced sediment deposition and hypersalinization

Increasing intensity and extent of dry-season fires

Linking Zambezi flow regime to wildlife diversity

- Wattled Crane breeding & feeding ecology as function of flooding patterns
- African buffalo status and ecology in relation to flooding patterns
- Changes in waterbird distribution and abundance over time

Vulnerable Wattled Cranes

- ~90% population emmigration
- Reduction in main food source (Eleocharis rush tubers)
- Increased nest vulnerability to fire
- Shift in breeding grounds from floodplain to escarpment

Bento et al. 2007

African buffalo

•Renown for largest concentration in Africa and vital ecological role as bulk grazer

• Dry season body condition linked to floodplain grassland moisture content

• Loss of carrying capacity related to drying and increased fire

Waterbirds of International Conservation Concern

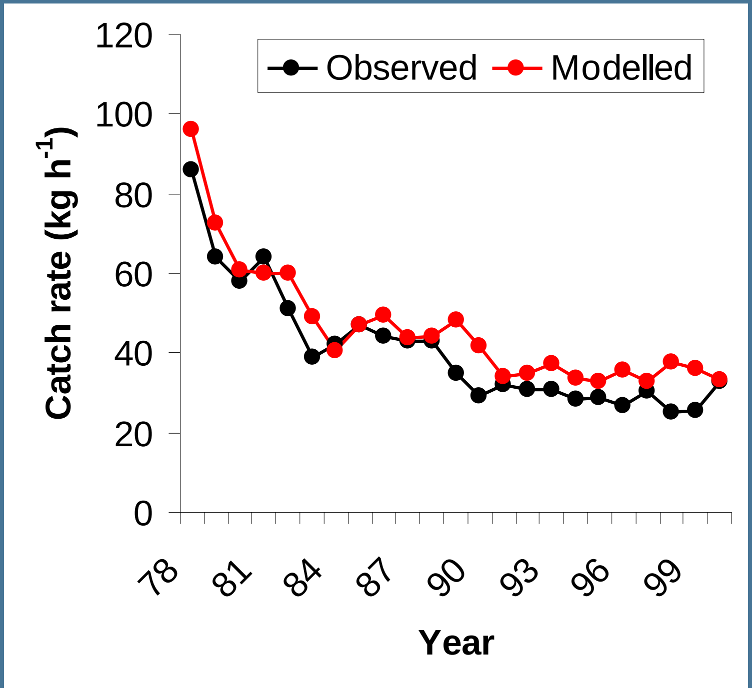



Linking Zambezi flow regime to ecosystem services and human livelihoods

- >800 hours of participatory rural appraisal along entire lower Zambezi
- Research on flow-related changes in prawn industry, subsistence and commercial agriculture and fisheries, grazing, and hunting (carrying capacity for trophy species)
- Economic valuation of flow-related ecosystem services
- Changes in access to domestic water supply, sanitation, cultural use of water

Prawn production

- Life-cycle depends on wet season flood pulse and dry season low flows
- Strong correlation between Zambezi annual runoff pattern and fishery catch rate
- Lost economic value $US10-20 million per annum



Gammeslrod 1992; Hoguane 2002

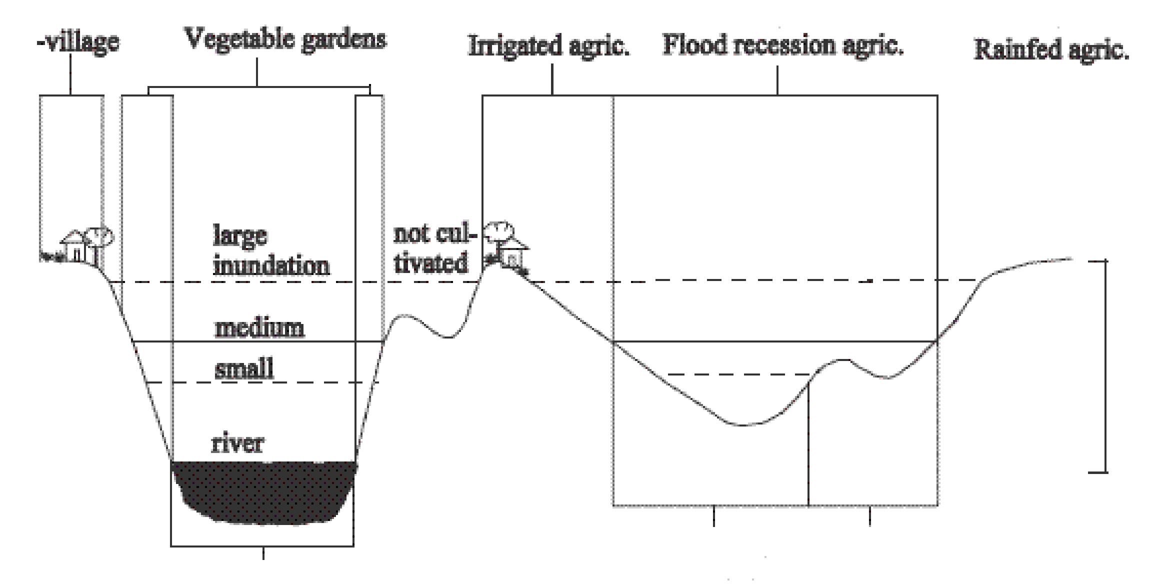
Freshwater fisheries

• Reduction in freshwater fisheries directly related to reduced flooded area and duration and mistimed flooding regime

• 30,000-50,000 tonnes per annum under natural flooding regime

•Highly responsive to large flooding events (2001, 2008)

Tweddle 2006



Flood-dependent agricultural systems

- Mistimed floods damage riverbank cropping; increase drought vulnerability
- Reduced area for flood recession crops linked to >30% productivity decline
- Salinity intrusion most significant threat to sugar production
- Economic valuation of annual floods for agriculture suggests $US millions/annum

Grazing lands

- Reduced extent and quality of end-of-dry season grazing lands for cattle
- Among limiting factors in post-war livestock recovery
- Lost economic value $US tens of thousands could be recovered

Water supply

- >5 m water table decline on delta floodplain due to diminished recharge

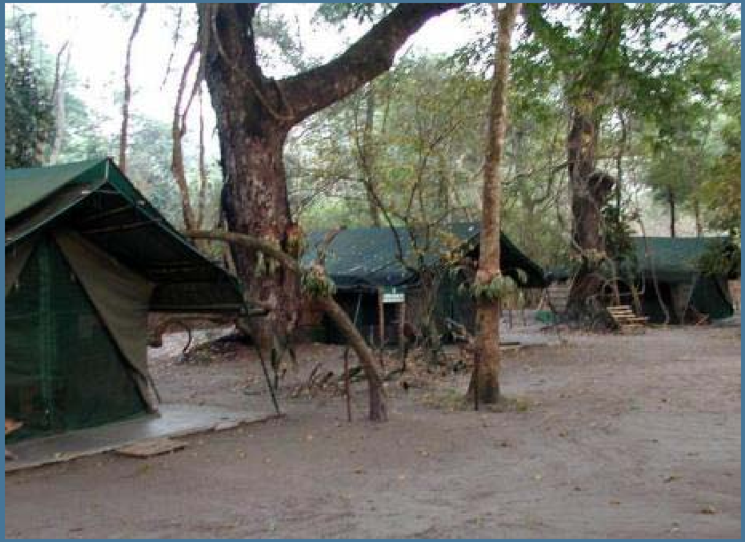
- Increasing dependence on Zambezi River to meet domestic water requirements—crocodiles, waterborne disease

- Guveya & Sukume (2008) estimated annual value of water - $US 9 million during normal/flood years and US$14 million during drought years.

Wildlife ecotourism and hunting

• 90-95% population reduction of large mammals during civil war--reduced annual flooding enabled year-round poaching operations – now recovering but may be limited by carrying capacity

• Trophy hunting value in $US millions per annum and critical local protein supply





Settlement and displacement

Further changes in settlement patterns (adaptation to loss of regular annual floods) result in higher social and economic costs during very large (uncontrollable) floods



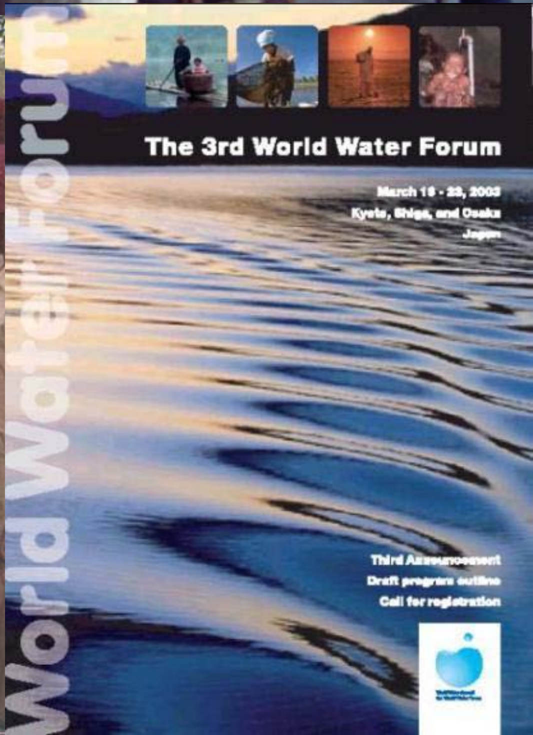

Cultural values

• Ceremonial, recreational, aesthetic, and spiritual values affected by changes in flow regime

• Improvements linked to restoration of more natural flow regime

Economic value of water for downstream ecosystem services (livelihoods) exceeds value of water for strict hydropower production—even without valuation of biodiversity and culture

Forums for ongoing information sharing



"Outflow from Cahora Bassa Dam must be managed such that simulation of the natural seasonal and inter-annual changes in water flow in the Zambezi River are re-established. This should include wet season flows of greater magnitude, and dry season flows of lesser magnitude, than are presently released, to re-introduce the essential hydrologic variability required for the proper functioning of the river and the floodplain ecosystems and communities that it supports. If this strategy is not adopted, the social, economic, and ecological costs for Mozambique will far outweigh the costs of implementation."

Participant statement from the Workshop on the Sustainable Use of Cahora Bassa Dam and Zambezi Valley, 2 October 1997, hosted by Hidroelectrica de Cahora Bassa

INTERNATIONAL CRANE FOUNDATION

Zambezi Delta research and management 1995-present

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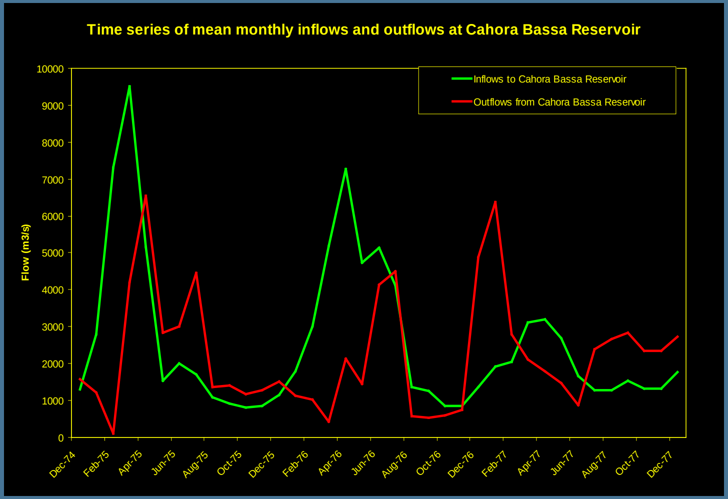


Environmental flows

*Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems **and** the human livelihoods and well-being that depend on these ecosystems.*

(Brisbane Declaration 2007)




Modeling water availability for environmental flows

1. Assess the likelihood that different e-flow scenarios can be achieved (measured as target outflow reliability), constrained by water availability and hydropower contracts

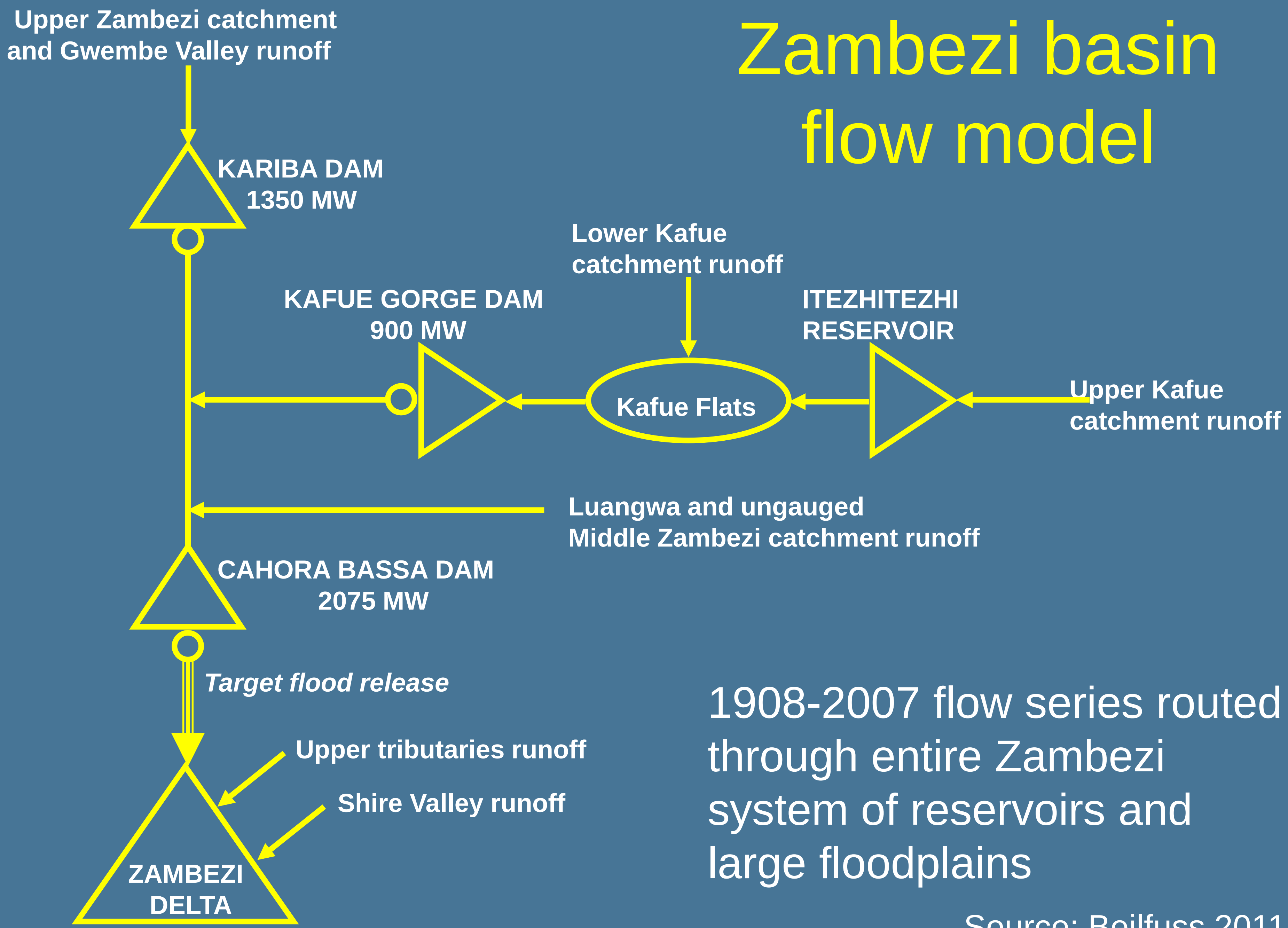
2. Hydropower: assess the affect of each e-flow alternative on firm power generation and total annual energy production

3. Water availability: sensitivity of 100-year flow series to increased water abstractions and reduced runoff (climate change)

Cahora Bassa Dam

- 2440 m3/s MAR; CV = 0.36
- Short reservoir residence time (8 months) -- frequent spillage resulting in lower economic cost for e-flows
- Spillway intakes located low on dam wall, enabling e-flow discharge opportunities for range of reservoir conditions

Zambezi basin flow model



1908-2007 flow series routed through entire Zambezi system of reservoirs and large floodplains

Source: Beilfuss 2011

Magnitude

- Three variations for magnitude
- The mean annual Zambezi Delta maximum flow prior to regulation was greater than 10,000 m^3/s (upper limit for target releases)
- Bankful discharge in the Zambezi Delta is approximately 4500 m^3/s (lower limit)
- Intermediate flow release of 7000 m^3/s

Timing

- Two variations for timing
- Natural (pre-dam) flood season onset in December
- Natural (pre-dam) maximum flows in February

Duration

- Three variations for flow duration (of flows equal to or exceeding target discharge)

- 8 weeks duration set as upper limit based on water availability (avg. duration of flooding prior to regulation was 12 weeks)
- 2 weeks duration for lower limit
- 4 weeks duration for intermediate level

“Predictability”

- Frequency (% of years) that target flood flows are met or exceeded in Zambezi Delta

E-flow scenario	Zam Delta desired flow (m^3s^{-1})	Req'd magnitude CB Discharge (m^3s^{-1})	Timing CB Discharge	Duration CB Discharge	Assumed downstream inflow (m^3s^{-1})
Baseline	--	--	--	--	--
1	4500	3700	Dec	2 weeks	800
2	4500	3700	Dec	4 weeks	800
3	**4500**	**2750**	**Feb**	**2 weeks**	**1750**
4	**4500**	**2750**	**Feb**	**4 weeks**	**1750**
5	4500	3375	Dec+Jan	8 weeks	1125
6	4500	2825	Feb+Mar	8 weeks	1675
7	7000	6200	Dec	2 weeks	800
8	7000	6200	Dec	4 weeks	800
9	7000	5250	Feb	2 weeks	1750
10	7000	5250	Feb	4 weeks	1750
11	**7000**	**5875**	**Dec+Jan**	**8 weeks**	**1125**
12	7000	5325	Feb+Mar	8 weeks	1675
13	10000	9200	Dec	2 weeks	800
14	10000	9200	Dec	4 weeks	800
15	10000	8250	Feb	2 weeks	1750
16	10000	8250	Feb	4 weeks	1750
17	10000	8875	Dec+Jan	8 weeks	1125
18	10000	8325	Feb+Mar	8 weeks	1675

E-flow Scenario	Target outflow reliability (%)	Baseline outflow reliability (%)	Firm power reliability (%)	Energy production (GWh/yr)	Energy as % of baseline
Baseline	**--**	**--**	**98.4**	**14393**	**100.0**
Firm Power = 1370 MW continuous; present day operation practices					
2	94.5	58.2	96.7	14273	99.2
3	97.8	7.7	97.3	14407	100.0
4	97.8	7.7	97.1	14357	99.7
5	92.3	42.9	94.2	14083	97.8
6	95.6	2.2	95.1	14355	99.7
7	94.5	29.7	96.2	14186	98.6
8	89.0	2.2	92.9	13722	95.3
9	94.5	3.3	95.8	14064	97.7
10	91.2	3.3	92.5	13637	94.7
11	72.5	4.4	89.7	13112	91.1
12	78.0	1.1	83.9	12963	90.1
13	89.0	5.5	93.3	13801	95.9
14	78.0	0.0	90.9	13067	90.8
15	90.1	2.2	92.2	13612	94.6
16	83.5	1.1	90.0	12993	90.3
17	24.2	0.0	87.0	12575	87.4
18	25.3	0.0	68.0	12018	83.5

E-flow Scenario	**Target outflow reliability (%)**	**Baseline outflow reliability (%)**	**Firm power reliability (%)**	**Energy production (GWh/yr)**	**Energy as % of baseline**
Baseline	--	--	98.4	14393	100.0
1	95.6	85.7	97.3	14333	99.6
2	94.5	58.2	96.7	14273	99.2
3	**97.8**	**7.7**	**97.3**	**14407**	**100.0**

Change Level 3 = 4500 m^3s^{-1} discharge for 2 weeks in February – achieved while maintaining >97% firm power and with no reduction in annual energy production. Target outlfows achieved in ~98% of all years, compared to less than 8% of years with current management practices

10	91.2	3.3	92.5	13637	94.7
11	72.5	4.4	89.7	13112	91.1
12	78.0	1.1	83.9	12963	90.1
13	89.0	5.5	93.3	13801	95.9
14	78.0	0.0	90.9	13067	90.8
15	90.1	2.2	92.2	13612	94.6
16	83.5	1.1	90.0	12993	90.3
17	24.2	0.0	87.0	12575	87.4
18	25.3	0.0	68.0	12018	83.5

Is there water available for e-flows given constraints for hydropower production?

• YES--A range of short-duration, high volume flows are possible depending on desired magnitude, duration, and timing of releases

•With slight reductions in hydropower, many target flow patterns (higher magnitude, longer duration) could be realized downstream

• Conjunctive management of Zambezi dams would further increase the opportunity for generating e-flows with minimum reduction in hydropower--but much can be achieved with Cahora Bassa releases

• E-flows could help ameliorate climate change flow reductions if power production commitments realigned

Modeling trade-offs among water users

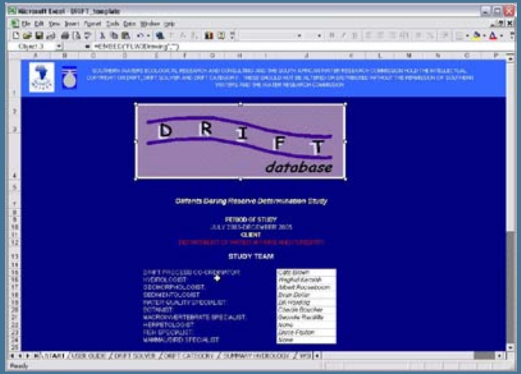
1. What are the trade-offs in water requirements (magnitude, duration, timing) among the different users
2. What are the "minimum" flood requirements (defined in terms of magnitude, duration, timing)?
3. Are the "minimum" flood requirements realistic with respect to the hydropower generation?

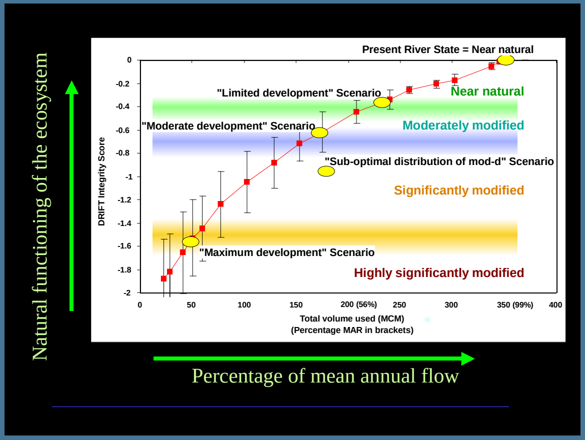



DRIFT

Downstream Response to Imposed Flow Transformations

A holistic, scenario-based environmental flows methodology applied to the lower Zambezi River





Different water users/concern in the delta

- Irrigated commercial agriculture
- Small scale agriculture (subsistence and cash crop)
- Estuarine and coastal fisheries (esp. prawns)
- Freshwater fisheries
- Livestock
- Large mammals
- Vegetation communities (including invasive species)
- Natural resource utilisation (socio-economic and cultural)
- Water quality
- Domestic water supply
- In-river navigation
- Waterbirds (as a proxy for wetland biodiversity)
- Public health
- Settlement patterns

Flow changes considered for the Zambezi Delta

The three flow categories were:

- Dry season lowflows (PD + 5)
- The ‘annual’ flood (PD + 18)
- 1:5 year return flood (PD + 1)

The flow changes encompass a mixture of:
Changes in magnitude.
Changes in duration.
Changes in timing.

Specialist’s evaluations

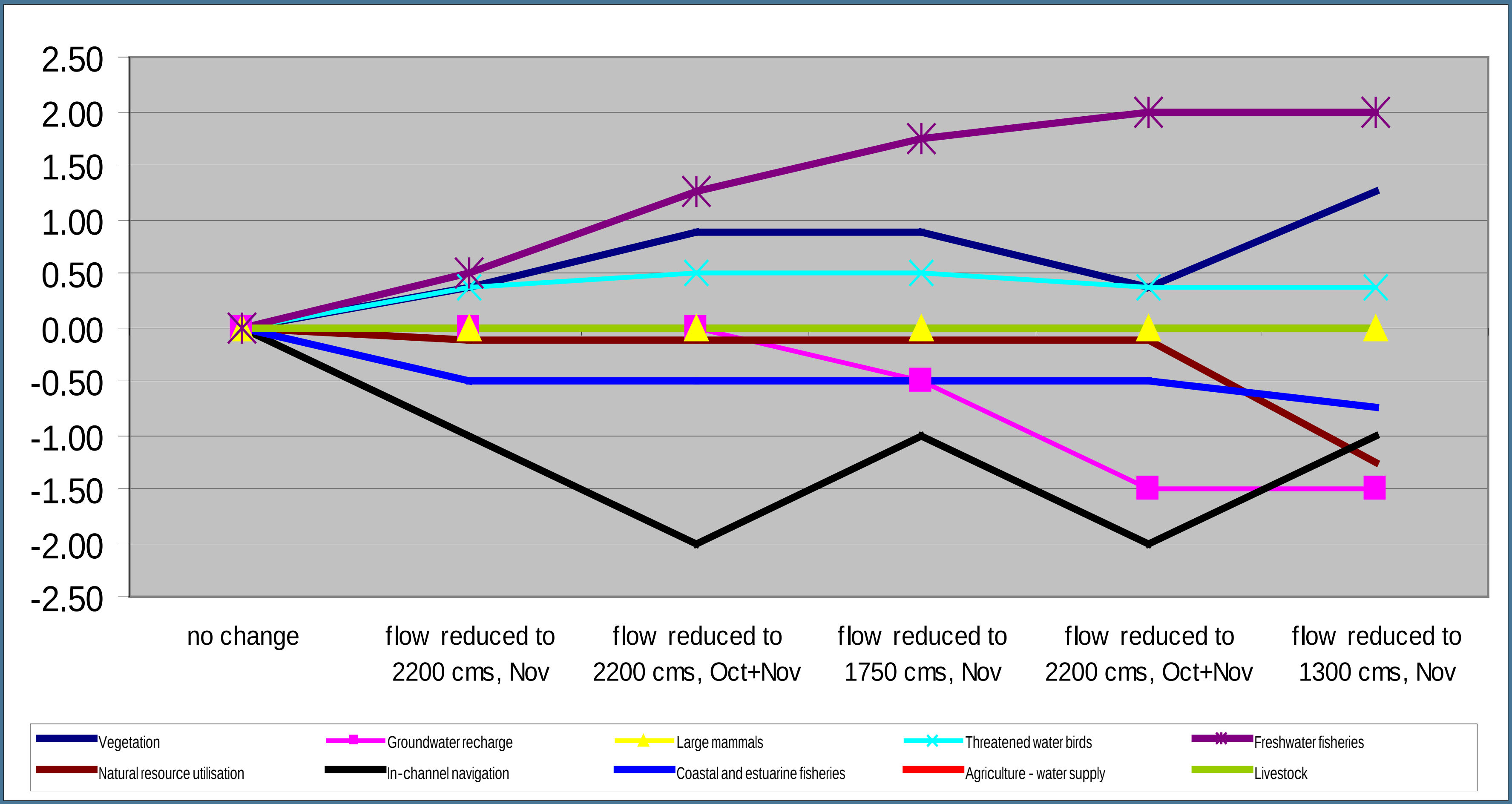
- Select key items for consideration
- Define target condition
- Describe direction of change
- Describe whether item increase or decrease
- Severity scores: 0-5:

    0 = no change

    5 = 100% attain target

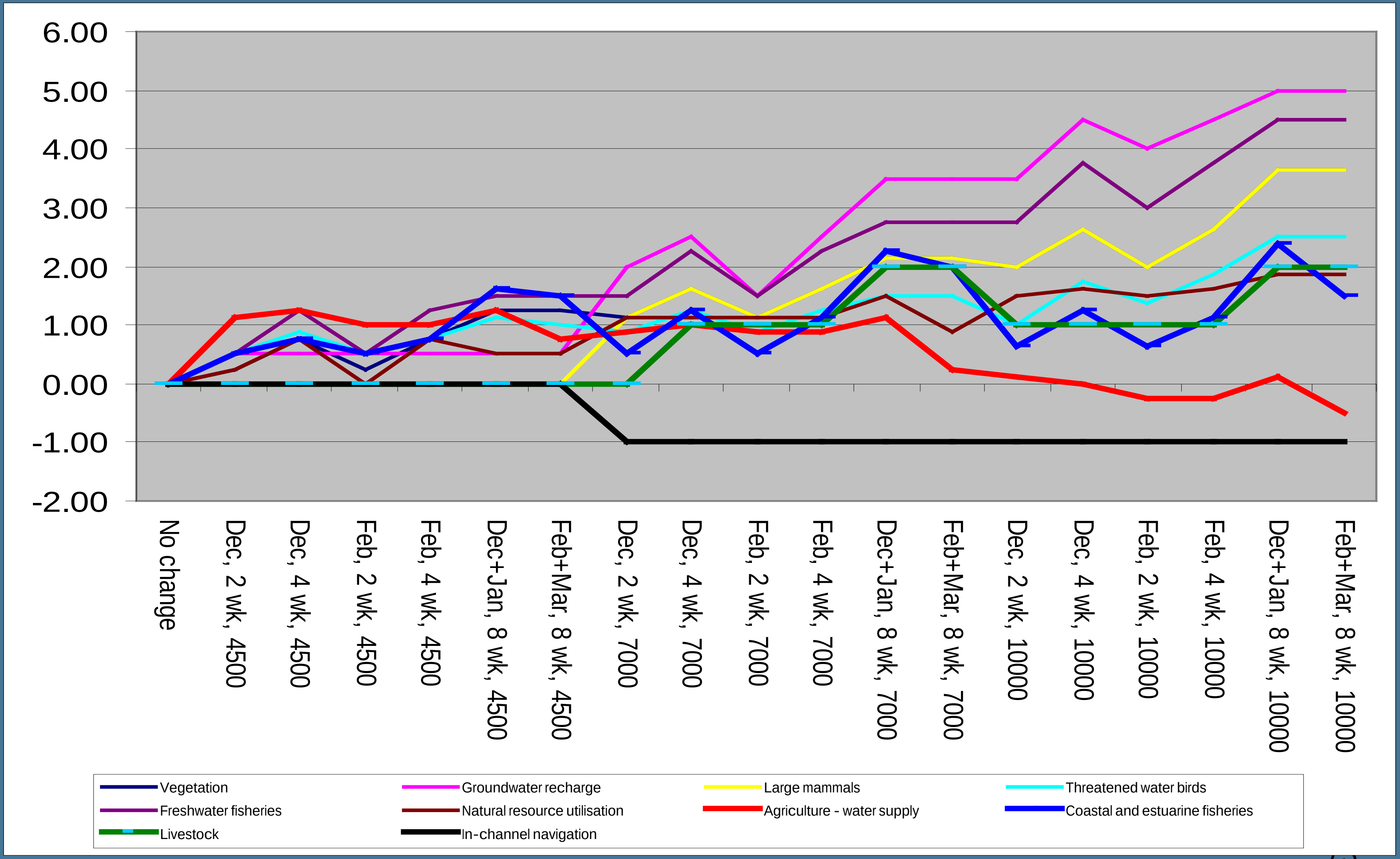
    -5 = twice as far away from target as present

Trade-offs among users?
Dry season low flows



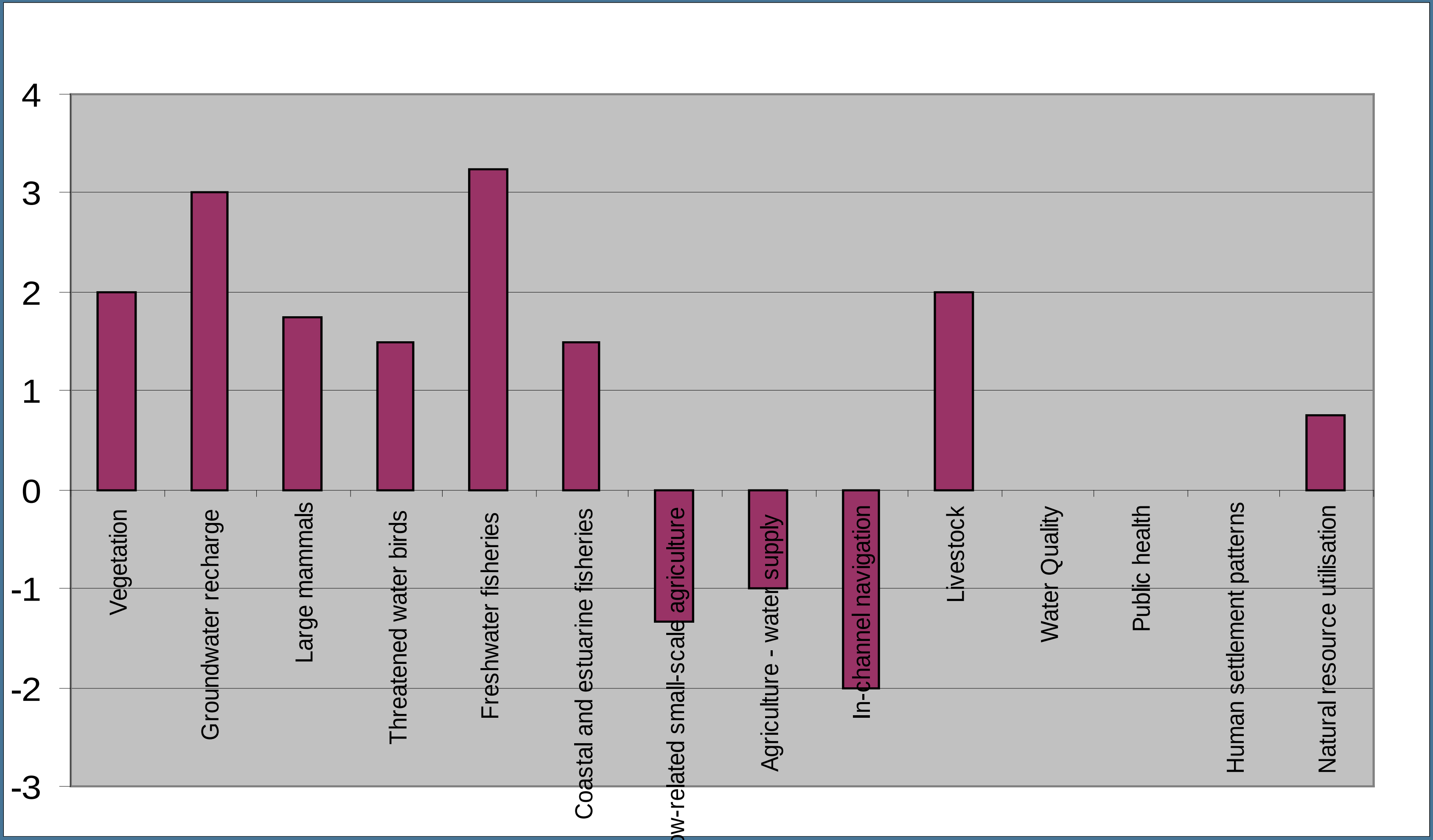
Beilfuss and Brown 2009

Trade-offs among users? Annual floods



Beilfuss and Brown 2009

Trade-offs among users?
1:5 year flood event



Beilfuss and Brown 2009

Are there significant trade-offs among downstream water use requirements?

- NO--users show consistent need for improve flows in the delta
- Strong consensus between specialists.
- Annual flood is most favoured overall, value increases with magnitude and duration for most users
- Many favour 1:5 year flood—periodic large floods are unavoidable
- At least one scenario indicates possibility of improvements with no hydropower reduction, and several scenarios indicate a range of benefits with modest hydropower reductions

Implementation of Environmental Flows and Zambezi Delta restoration

Environmental flows partnership for Zambezi River basin was conceived at the 3rd Zambezi River Basin Stakeholders Forum (November 2007 in Victoria Falls)

Partnership between Zambezi basin operators and water authorities (HCB, ZRA, ZESCO, ARA-Z), and ICF, WWF, UNESCO-IHE, and regional universities

Project team (African) based in Zambezi basin with advisory group drawn from regional and international expertise

Shared challenges/issues identified by Zambezi basin operators for collaboration with environmental flows partnership

1. Environmental Flows

- Data gathering and information sharing
- Flow scenario development
- Monitoring and adaptive management
- Capacity building and personnel exchange
- Water quality as well as quantity

2. Conjunctive Dam Management

- Governance
- Technical operations
- Benefit sharing

Shared challenges/issues identified by Zambezi basin operators for collaboration with environmental flows partnership

3. Managing extreme floods and droughts

- Forecasting
- Infrastructure
- Climate change
- Emergency preparedness

Reflections

- Think big and simplify complexity as needed to move forward

- Reframed issue as regional challenge of equity in shared water resources -- balancing upstream and downstream water use rather than pitting trade-offs between water for people and water for wildlife

- Strived for common understanding with stakeholders (especially water resource authorities) rather than antagonistic interactions-ex. importance of emphasizing benefits as well as costs of river regulation

- Concerted effort to understand community perspectives on how river flows affect their lives, both good and bad

Reflections

- Used cross-sectoral, multi-disciplinary approach to collect, integrate, model, and analyze information for improved understanding of key linkages

- Frequently disseminated research results and background information to wide array of stakeholders through forums and all available media to promote a shared understanding

- The process of institutionalizing new operating rules for dams requires commitment of staff and resources over a significant period of time.

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